20th Century 3DUI Bib:
Annotated Bibliography of 3D User Interfaces of the 20th Century

Compiled by Ivan Poupyrev and Ernst Kruijff, 1999, 2000, 3rd revision

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1. Adelstein, B., Johnston, E., Ellis, S., A testbed for Characterizing Dynamic Response of Virtual Environment Spatial Sensors. *Proceedings of UIST'92*. 1992. ACM. pp. 15.
Keywords: *input devices, sensor lag, spatial sensors, system calibration*
Annotations: This paper describes a testbed for measuring the latency of spatial sensors, but unlike Liang et al. [UIST'91 paper] it does not suggest specific filtering methods. Unlike previous related work, this study measures the performance of the sensor alone. Factors such as code execution time, inter-process communication time, and rendering time do not distort the results.

2. Agronin, M., The Design of a Nine-String Six-Degree-of-Freedom Force-Feedback Joystick for Telemanipulation. *Proceedings of NASA Workshop on Space Telerobotics, 1987*. 1987. pp. 341-348.
Keywords: *haptics, force feedback, joystick, manipulation, teleoperation, telerobotics, virtual reality*
Annotations: Haptic Displays: A six-degree of freedom force feedback joystick. paper basically explains the joystick and how it works. Goes through the physics equations for its motion very painlessly.

3. Angus, I., Sowizral, H., Embedding the 2D Interaction Metaphor in a Real 3D Virtual Environment. *Proceedings of Stereoscopic Displays and Virtual Reality Systems, 2409*. 1995. SPIE. pp. 282-293.
Keywords: *pen & tablet metaphor, constrained interaction, 3D interface, virtual reality, 2D metaphor*
Annotations: The first published system that presented a standard 2D GUI within a 3D virtual environment. Used to allow Web browsing in a VE.

4. Angus, I., Sowizral, H., VRMosaic: web access from within a virtual environment. *IEEE Computer Graphics & Applications*, 1996. 16(3): pp. 6-10.
Keywords: *pen & tablet metaphor, constrained interaction, 3D interface, virtual reality, 2D metaphor*
Annotations: A journal version of the system reported in 1995 at the SPIE conference

5. Ayers, M., Zeleznik, R., The Lego Interface Toolkit. *Proceedings of UIST'96*. 1996. ACM. pp. 97-98.
Keywords: *lego blocks, rapid input device protoyping, 3D input device, 3D interfaces, virtual reality,*
Annotations: A novel approach to rapid prototyping of interaction devices for 3D interaction and virtual environments. The devices are built out of the Lego (tm) building blocks with sensors mounted on them simply by snapping them together.

6. Badler, N., Manoochehri, K., Baraff, D., Multi-Dimensional Input Techniques and Articulated Figure Positioning by Multiple Constraints. *Proceedings of Workshop on Interactive 3D Graphics*. 1986. ACM. pp. 151-169.
Keywords: *multi-dimensional input, jacks, constraints, clutching, physical props*
Annotations: This paper describes an attempt to add multi-dimensional input, using a Polhemus tracker, to an early version of Badler's "Jack" articulated figure positioning system. The Polhemus ("wand") was used in two modes: absolute and relative. Absolute positioning was fatiguing. Relative motion allowed the user to move the wand (by releasing the button) when an uncomfortable position was reached. Orientation was always absolute. The implementers thought that the consistent coordinate systems of the wand and their "test scene" would allow intuitive movement, but this was not true. Lack of depth perception ("spatial feedback") on the 2D display made it difficult to select a target; also, simultaneously positioning and orienting the wand proved to be challenging. They tried decoupling wand parameters, but results were still not satisfactory. Using the wand to position a virtual camera was more successful but it was still a consciously calculated process. The implementers found that using a real object as a spatial reference for 3D wand interactions yielded a "natural and effortless" interface. The real object provides the true depth information lacking in the 2D display.

7. Balakrishnan, R., Fitzmaurice, G., Kurtenbach, G., Singh, K., Exploring Interactive Curve and Surface Manipulation Using a Bend and Twist Sensitive Input Strip. *Proceedings of Symposium on Interactive 3D Graphics*. 1999. ACM. pp. 111-118.
Keywords: *input devices, bimanual input, ShapeTape, gestures, curves, surfaces*
Annotations: This paper describes input device made of a continuous bend and twist sensitive strip that is used to edit and create 3D curves and surfaces. In addition the paper also talks about other interaction techniques including command access and system control.

8. Beaten, R., DeHoff, R., An Evaluation of Input Devices for 3-D Computer Display Workstations. *Proceedings of The International Society for Optical Engineering 1987*. 1987. SPIE. pp. 237-244.
Keywords: *input devices, user study, stereoscopic cues, manipulation, positioning, trackball*
Annotations: Describes a user study (16 subjects) testing a 3D positioning task using 3D trackball (free space movements), mouse (three buttons used as mode control for motion in the three orthogonal planes), and a custom thumbwheel device (three wheels, one-handed control,

arranged to correspond to orientation of display's coordinate system). Output strategies were: perspective encoding of depth and field-sequential stereoscopic encoding of depth. Thumbwheels yielded a more than two-fold increase in positioning accuracy as compared to the other devices. The stereoscopic display reduced positioning error by about 60%. Also, the relative differences between input devices varied across the display conditions, but in general positioning accuracy increased 51-60% with the stereoscopic display. Positioning time: The time associated with the mouse was longer than the other two devices. Positioning with either the trackball or the thumbwheels was about 23% faster.

9. Begault, D., *3D Sound For Virtual Reality and Multimedia*. 1994: Academic Press. pp. .
Keywords: *virtual auditory space, 3D sound, spatial hearing, HRTF, VR, multimedia*
Annotations: This book is one of the first on 3D sound for virtual reality. It provides introductions to the psychoacoustics of spatial sound and implementing virtual acoustics through digital signal processing.

10. Bier, E., Skitters and Jacks: Interactive 3D Positioning Tools. *Proceedings of Workshop on Interactive 3D Graphics*. 1986. ACM. pp. 183-196.
Keywords: *placement techniques, cursor, skitter, jack, 3D object placement, desktop 3D interfaces*
Annotations: Describes an early version of Bier's "Gargoyle 3D" system. The interactive techniques are primarily geared towards scene composition, including precise placement of objects using affine transforms. Anchors: A "hot spot" used, for example, to select an axis of rotation. End conditions: e. g., the number of degrees to rotate. Jacks: Cartesian coordinate frames used to describe anchors & end conditions. Skitter: 3D cursor (interactively positioned Jack). Uses a gravity function for effective 3D point selection.

11. Bier, E., Snap-dragging in three dimensions. *Proceedings of Symposium on Interactive 3D Graphics*. 1990. ACM. pp. 193-204.
Keywords: *3D interfaces, constraints, manipulation, desktop 3D, mouse and keyboard, gravity, scene composition*
Annotations: The paper describes an interface introducing "snapping" of interface elements to each other in the context of 3D interactive scene creation. Gravity functions are used to implement snapping, for example a 3D cursor can snap to various elements of the scene., making it easier to select scene elements. System also uses various alignement objects, e.g. lines, planes and spheres which other scene objects can snap to and which can be used as guides for manipulating object.

12. Billinghurst, M., Put That Where? Voice and Gesture at the Graphic Interface. *Computer Graphics*, 1998. 32(4): pp. 60-63.
Keywords: *multimodal interaction, 3D interfaces, manipulation, voice input, gesture input*
Annotations: Survey of various issues in multimodal interaction with 3D user interfaces in mind.

13. Billinghurst, M., Baldis, S., Matheson, L., Phillips, M., 3D pallette, a virtual reality content creation tool. *Proceedings of VRST'97*. 1997. ACM. pp. 155-156.
Keywords: *Tablet, multimodal input, modeling, 3D user interfaces, pen input*
Annotations: Describes an application which uses a tablet, 6DOF direct input and multimodal input, for rapid scene creation. The user can draw on the tablet, tracked in 3D using magnetic sensor and the 3D objects would "pop out" from the tablet, can be picked up and manipulated in virtual space.

14. Bliss, J., Tidwell, P., Guest, M., The effectiveness of virtual reality for adminestering spatial navigation training to firefighters. *Presence: Teleoperators and Virtual Environments*, 1997. 6(1): pp. 73-86.
Keywords: *spatial orientation, training, knowledge transfer, wayfinding, navigation, VR*
Annotations: Article on knowledge transfer issues between virtual and real environments. Though domain specific, it provides several useful insights in what kinds of knowledge are transferred.

15. Bolt, R., "Put-that-there": voice and gesture at the graphics interface. *Proceedings of SIGGRAPH'80*. 1980. ACM. pp. 262-270.
Keywords: *pointing, 3D interaction, interaction technique, multimodal interaction*
Annotations: 1. The work described involves the user commanding simple shapes about a large-screen graphics display surface. Because voice can be augmented with simultaneous pointing, the free usage of pronouns becomes possible, with a corresponding gain in naturalness and economy of expression. Conversely, gesture aided by voice gains precision in its power to reference. 2. One of the first papers that describes interface that involved spatial interaction. The paper features using of magnetic sensor, which was a novelty in those days, for selecting objects and moving them with voice commands.

16. Bolter, J., Hodges, L., Meyer, T., Nichols, A., Integrating perceptual and symbolic information in VR. *IEEE Computer Graphics & Applications*, 1995. 15(4): pp. 8-11.
Keywords: *VR, menus, 3D interface, symbolic communication in VR, virtual text*
Annotations: This paper argues that user interfaces for VR should provide means to present and manipulate symbolic, textual information. A number of tasks where textual information is be needed are discussed: menu selection, presentation of numerical/statistical information, and presentation of narrative information, i.e. annotations.

17. Bordegoni, M., Gesture Interaction in a 3D User Interface. GMD, Darmstadt: *Technical Report ERCIM-93-R019*. 1993.
Keywords: *Gesture interaction, manipulation, navigation, feedback, 3D interaction, virtual reality, glove input, multimodal interaction*
Annotations: Report on gesture interaction issues, describing a dynamic gesture language, needed feedback, a framework for a gesture system and several examples of gesture interaction in 3D user interfaces.

18. Bowman, D., Davis, E., Badre, A., Hodges, L., Maintaining Spatial Orientation during Travel in an Immersive Virtual Environment. *Presence: Teleoperators and Virtual Environments*, 1999. 8(6): pp. 618-631.
Keywords: *taxonomy, navigation, spatial awareness, 3D maps, route-planning technique, VR, 3D user interfaces*
Annotations: This paper discusses a new taxonomy for virtual travel techniques and runs an experiment comparing three common travel metaphors. The experiment tests subjects' ability to remember the spatial relationship of an

object to the user's location after traveling through a virtual maze.

19. Bowman, D., Hodges, L., An evaluation of techniques for grabbing and manipulating remote objects in immersive virtual environments. *Proceedings of Symposium on Interactive 3D Graphics*. 1997. ACM. pp. 35-38.
Keywords: *3D interaction techniques, manipulation, virtual reality, selection, evaluation*
Annotations: User study of simple manipulation techniques.

20. Bowman, D., Hodges, L., Formalizing the Design, Evaluation, and Application of Interaction Techniques for Immersive Virtual Environments. *The Journal of Visual Languages and Computing*, 1999. 10(1): pp. 37-53.
Keywords: *3D interaction, interaction techniques, taxonomy, testbed evaluation, manipulation, navigation, selection, user tasks, VR*
Annotations: This article presents a methodology for designing, testing, and applying 3D interaction techniques in virtual environments. Taxonomies of techniques for travel, selection, and manipulation are discussed. The concepts of guided design and testbed evaluation are presented and examples are given. This is a summary of the methodology used in Bowman's dissertation.

21. Bowman, D., Johnson, D., Hodges, L., Testbed Evaluation of VE Interaction Techniques. *Proceedings of VRST'99*. 1999. ACM. pp. 26-33.
Keywords: *formal evaluation, interaction techniques, manipulation, VR*
Annotations: Testbed evaluation is a type of experimentation which attempts to obtain richer results by considering multiple independent and dependent variables. Here, two experiments and their results are described which test the performance and usability of techniques for the tasks of travel and selection/manipulation.

22. Bowman, D., Wineman, J., Hodges, L., Allison, D., Designing Animal Habitats Within an Immersive VE. *IEEE Computer Graphics & Applications*, 1998. 18(5): pp. 9-13.
Keywords: *immersive design, pen and tablet metaphor, virtual manipulation, 3D interaction, immersive virtual reality, HMD*
Annotations: The Virtual Habitat is an immersive VE which allows architects to redesign an animal habitat. This requires some complex and well-integrated interaction techniques for user travel and object manipulation.

23. Bowman, D.A., Koller, D., Hodges, L.F., Travel in immersive virtual environments: an evaluation of viewpoint motion control techniques. *Proceedings of IEEE VRAIS'96*. 1997. pp. 45-52.
Keywords: *virtual reality, VR, 3D user interface, 3D interaction, navigation, viewpoint control, user study, experiments, interaction techniques*
Annotations: Three formal experiments comparing common travel techniques

24. Britton, E., Lipscomb, J., Pique, M., Making nested rotations convenient for the user. *Proceedings of SIGGRAPH'78*. 1978. ACM. pp. 222-227.
Keywords: *3D manipulation, 3D interaction, input devices, 3D user interfaces, interactive rotations*
Annotations: The early work which investigated the modes of interactive rotations using 6DOF input devices. The authors coin the term "kinaesthetic correspondence" a principle for 3D interface design which postulates that manipulated 3D object (which they called "subimage") should move in the same direction as user's hand.

25. Brooks, F., Grasping Reality Through Illusion: Interactive Graphics Serving Science. *Proceedings of CHI'88*. 1988. ACM. pp. 1-11.
Keywords: *3d interaction, framework, human factors*
Annotations: 1. A very good paper with many useful insights on varying topics in 3D interaction / virtual reality. Includes his "shells-of-certainty" model for user interface research. 2. Good review of the various issues in VR and interactive 3D computer graphics up to 1988. However, many issues are still valid and probably will be valid for a while.

26. Brooks, F., Ouh-Young, J., Batter, J., Kilpatrick, P., Project GROPE- Haptic Displays for Scientific Visualization. In *SIGGRAPH'90*. 1990, ACM. pp. 177-185.
Keywords: *haptics, display, visualization, virtual reality, manipulation*
Annotations: Describes long-term research effort into haptic ("pertaining to sensations such as touch, temperature, pressure, etc. mediated by skin, muscle, tendon, or joint") displays for molecular docking. Interesting as an example of how to develop a system for real users. Haptic displays are of limited application, but when they are applicable, a performance increase of approximately 2x is measured over pure visual stimuli. Some interesting results on 3D/6D manipulation: * Users of an imperfect-perception visual system tend to decompose three-dimensional positioning tasks into several separate subtasks, each of lower dimensionality * Even in real space, subjects usually decompose 6D docking tasks into 3D positioning alternating with 3D rotations. More than 2D motions are rarely observed in virtual space.

27. Bukowski, R., Sequin, C., Object Associations: A Simple and Practical Approach to Virtual 3D Manipulation. *Proceedings of Symposium on Interactive 3D Graphics*. 1995. ACM. pp. 131-138.
Keywords: *constraints, smart objects, 3D manipulation*
Annotations: Presents a framework within which objects can be given intelligence about their proper positions and orientations within a 3D space to aid in manipulation

28. Burdea, G., *Force and Touch Feedback for Virtual Reality*. 1996: Wiley Interscience. pp. .
Keywords: *haptic sensing, actuators, tactile feedback, physical modeling, force feedback, display devices*
Annotations: Provides a comprehensive introduction and reference on force-feedback.

29. Butterworth, J., Davidson, A., Hench, S., Olano, T., 3DM: a three dimensional modeler using a head-mounted display. *Proceedings of Symposium on Interactive 3D graphics*. 1992. ACM. pp. 135-138.
Keywords: *3D interaction, 3D interface toolkit, direct manipulation, interaction techniques, metaphor, navigating, virtual reality, manipulation, input devices, modeler*
Annotations: 1. This article belongs to the roots of VR aided modelers and exploration of input devices. 2. The pioneering paper that introduced many of the most basic interaction techniques and ideas for 3D interfaces and virtual reality. 3. Describes a 3D CAD system for use in a HMD. Has support for multiple navigation models: User "growing" and "shrinking" to allow work at multiple levels of detail; Walking (only within tracker range); Flying;

Grabbing the world (dragging & rotating). Uses rubber banding and predictive highlighting (e.g. gravity and plane/grid snapping) to aid in object selection. Simultaneous translation and rotation is helpful because it "concentrates more functionality into each operation" (thus saving time by requiring fewer total operations).

30. Buxton, W., Touch, Gesture, and Marking. In *Readings in Human-Computer Interaction: Toward the Year 2000*, R. Baecker, *et al*., Editors. 1995, Morgan Kaufmann.
Keywords: *taxonomy, chunking and phrasing, input devices, survey*
Annotations: 1. An excellent overview including device capabilities, taxonomy of input devices, chunking and phrasing, marking, gestures, and two handed input. Lots of good references to key papers in the area. 2. This is a survey which can be very useful for everybody who is working in 3D user interface design: indeed great many issues we face in designing 3D interfaces are similar or the same to those in 2D interfaces

31. Buxton, W., Myers, B., A Study in Two-handed Input. *Proceedings of CHI'86*. 1986. ACM. pp. 321-326.
Keywords: *two-handed input*
Annotations: 1. Valuable and classical survey on two-handed input 2. This is the classical work on 2 handed input. Although it does not directly relate to 3D user interfaces, it is probably a must read for everybody who plans to do work on 2 handed input in 3D.

32. Chen, M., Mountford, S.J., Sellen, A., A Study in Interactive 3-D Rotation Using 2-D Control Devices. *Proceedings of SIGGRAPH'88*. 1988. ACM. pp. 121-129.
Keywords: *object rotation, 2D input, desktop 3D interfaces, mouse, user studies, experimental evaluation*
Annotations: Chen studies four methods for using 2D input to rotate 3D objects: 1) Graphical sliders: A simple arrangement of horizontal sliders, one each for x, y, and z rotations. 2) Overlapping sliders: Uses vertical/horizontal mouse movement to control x and y rotations, while circular movement means z rotation. 3) Continuous XY + Z: 4) Virtual Sphere: Chen's user study indicated that the Virtual Sphere technique achieved the best results. He also compared the Virtual Sphere with a similar technique developed by Evans et al. [Evans 81]; no significant difference was found in mean time to complete simple or complex rotations, but users preferred the Virtual Sphere controller. The paper includes an appendix which describes the implementation of the virtual sphere in detail.

33. Chung, J.C., A comparison of Head-tracked and Non-head-tracked Steering Modes in the Targeting of Radiotherapy Treatment Beams. *Proceedings of Symposium on Interactive 3D Graphics*. 1992. ACM. pp. 193-196.
Keywords: *steering, tracking*
Annotations: This study compares four head-tracked and three non-head-tracked modes for changing position and orientation in the virtual world. Taken as a whole, head-tracked and non-head-tracked modes "differed very little". The test model was an abstract model consisting of colored spheres and a central target region. The user tried to find the best beam path to the target, which was defined as the beam path with minimum intersection of the beam and the spheres. All interaction modes were displayed on a HMD (N=14 subjects).

34. Conner, B., Snibbe, S., Herndon, K., Robbins, D., Zeleznik, R., *et al*., Three-dimensional widgets. *Proceedings of Interactive 3D graphics Symposium*. 1992. pp. 183-188.
Keywords: *3D interfaces, 3D widgets, interaction techniques, 3D interaction*
Annotations: The original paper that introduced 3D widgets for 3D interfaces as a first-class objects in the virtual environments.

35. Coquillart, S., Wesche, G., The virtual palette and the virtual remote control, a device and an interaction paradigm for the responsive workbench. *Proceedings of Virtual Reality'99*. 1999. IEEE. pp. 213-216.
Keywords: *transparent tablet, responsive workbench, magic lenses, two-handed interaction, props*
Annotations: The authors introduce a prop-like device, the Virtual Palette, a transparent tablet with a handle, tracked using magnetic sensor, which is used to interact with the responsive workbench. The user looks at the responsive workbench through the tablet, and the image on the workbench is registered with the tablet so that it appears to be on the surface of the tablet. The user can interact with the image by touching it on the physical tablet with a pencil tracked with magnetic sensor. Authors also describe the Virtual Remote Control Panel, a two-handed interaction technique, based on the Virtual Palette to control applications.

36. Cruz-Niera, C., Sandin, D., Defanti, T., Surround-Screen Projection-Based Virtual Reality: The Design and Implementation of the CAVE. *Proceedings of SIGGRAPH'93*. 1993. ACM. pp. 135-142.
Keywords: *virtual reality, VR, stereoscopic display, output devices, head tracking, projection paradigms, real-time manipulation, immersion*
Annotations: Describes the design and implementation the the Cave Automatic Virtual Environment, a 4 wall projection-based VR display system. The paper also goes into some detail on off-axis projections techniques.

37. Cugini, J., Laskowski, S., Sebrechts, M., Design of 3D Visualization of Search Results: Evolution and Evaluation. *Proceedings of 12th Annual International Symposium: Electronic Imaging 2000: Visual Data Exploration and Analysis*. 2000. IST/SPIE. pp. 198-210.
Keywords: *3D user interfaces, visualization, information retrieval*
Annotations: The paper discusses the evolution of the NIST Information Retrieval Visualization Engine (NIRVE). This prototype employs modern interactive visualization techniques to provide easier access to a set of documents resulting from a query to a search engine. The motivation and evaluation of several design features, such as keyword to concept mapping, explicit clustering, the use of 3-D vs. 2-D, and the relationship of visualization to logical structure are described.

38. Darken, R., Hands-off interaction with menus in virtual space. *Proceedings of Stereoscopic Displays and Virtual Reality Systems*. 1994. SPIE. pp. 365-371.
Keywords: *Menus, system control, visibility, readability*
Annotations: The author describes issues relating to the usage of menus in 3D virtual environments. A special focus was at visibility of menus in 3D and readability of fonts in VR. The author suggests a number of guidelines and principles on menu placement in VR.

39. Darken, R., Allard, T., Achille, L., Spatial Orientation and Wayfinding in Large-Scale Virtual Spaces: An Introduction. *Presence*, 1998. 7(2): pp. 101-107.
Keywords: *Wayfinding, navigation, spatial cognition, search methods*
Annotations: Excellent introduction to wayfinding issues

40. Darken, R., Cevik, H., Map usage in virtual environments. *Proceedings of VR'99*. 1999. IEEE. pp. 133-140.
Keywords: *wayfinding, maps, cues, map orientation, navigation, 3D interaction, VR*
Annotations: This article investigates how a map should be used during navigation in a virtual environment. Particularly, it is focuses especially on effect of forward-up and north-up maps orientation on user performance during wayfinding. The authors found correlation between map orientation, reference frame and search task.

41. Darken, R., Cevik, H., Map Usage in Virtual Environments: Orientation Issues. *Proceedings of Virtual Reality '99*. 1999. IEEE. pp. 133-140.
Keywords: *Wayfinding, maps, orientation*
Annotations: This article describes issues involved in the usage of maps into virtual environments. The authors conclude with guidelines for the usage of maps: via several tests, it was found out, that with egocentric search tasks, a forward-up map is preferable, whereas with exocentric search tasks, a north up performs best.

42. Deering, M., High Resolution Virtual Reality. *Computer Graphics*, 1992. 26(2): pp. 195-202.
Keywords: *desktop vr, head tracking*
Annotations: Talks about a desktop VR system which allows the user to work with a 3D tracker in a volume stereoscopically projected in front of the monitor. Good description of the math for head tracking. Also talks about taking into account the user's actual eye and distortions caused by the monitor glass.

43. Deering, M., The HoloSketch VR Sketching System. *Communications of the ACM*, 1996. 39(5): pp. 54-61.
Keywords: *3D modeling, output devices, input devices, 3D sketching*
Annotations: Describes how 2D sketching can be ported to VEs and reports on several issues, like menu systems.

44. Doellner, J., Hinrichs, K., Interactive, Animated 3D Widgets. *Proceedings of Computer Graphics International '98*. 1998. IEEE. pp. 278-286.
Keywords: *3D widgets, behavior, visual language, system control*
Annotations: This paper describes an object-oriented architecture for interactive, animated 3D widgets. Two types of directed acyclic graphs (geometry graphs and behavior graphs) on which operations are performed through high-level interfaces. A visual language for 3D widgets allows the developer to interactively construct 3D applications.

45. Draper, M., Exploring the Influence of a Virtual Body on Spatial Awareness, in *Department of Engineering*. 1995, University of Washington: Seattle.
Keywords: Spatial awareness, wayfinding, virtual body, distance estimations
Annotations: Master thesis exploring a broad number of factors relating to spatial awareness, especially those resulting from using a virtual body. Reports that no specific positive effects of using a virtual body on users spatial awareness were found.

46. Elvins, T., Nadeau, D., Kirsh, D., Worldlets - 3D Thumbnails for Wayfinding inn Virtual Environments. *Proceedings of UIST'97*. 1997. pp. 21-30.
Keywords: *virtual reality, navigation, viewpoint control, 3D interaction techniques, wayfinding, landmark knowledge, WIM*
Annotations: Interesting article which describes the usage of so called Worldlets, 3D thumbnails representing a landmark in a virtual environment, to support wayfinding.

47. Encarnacao, L., Bimber, O., Schmalstieg, D., Chandler, S., A Translucent Sketchpad for the Virtual Table. *Computer Graphics Forum*, 1999. 18(3): pp. 277-286.
Keywords: *Two-handed interaction, virtual workbench, gestural interaction, props, see-through tools*
Annotations: A discussion of a two-handed pen and pad style interaction method for a virtual workbench. A detailed explanation of a 2D pen gesture recognition technique is given.

48. Encarnacao, L., Fechter, J., Grunert, T., Strasser, W., A Platform for User-Tailored Interaction Development in 2D, 3D and VR. *Computer Graphics Forum*, 1996. 15(3): pp. 432-441.
Keywords: *User interface design, interaction objects, virtual interfaces*
Annotations: A platform for the development, integration and user-centered evaluation of interaction techniques. A message-passing layer communicates with a series of application objects representing 2D, 3D and VR.

49. Evans, K.B., Tanner, P.P., Wein, M., Tablet-based Valuators that Provide One, Two, or Three Degrees of Freedom. *Computer Graphics*, 1981. 15(3): pp. 91-97.
Keywords: *positioning techniques, desktop 3D user interfaces, stylus, rotation*
Annotations: Describes various ways of mapping stylus motion to valuators. One of his 3DoF techniques is similar to the Virtual Sphere; Chen compares it to the Virtual Sphere in his paper [Chen 1988]. Evans also discusses an automatic vernier motion (fine positioning) technique.

50. Feiner, S., MacIntyre, B., Knowledge-Based Augmented Reality. *Communications of the ACM*, 1993. 36(7): pp. 53-61.
Keywords: *augmented reality, AR, HMD, see-through*
Annotations: Describes a system which employs a see-through head mounted display (augmented reality) and projects wireframe graphics onto objects in the real world. An example given is an application which overlays a laser printer with wireframe information to help the user perform maintenance tasks. The head mount is constructed using a Private Eye.

51. Feiner, S., MacIntyre, B., Haupt, M., Solomon, E., Windows on the world: 2d windows for 3d augmented reality. *Proceedings of UIST'93*. 1993. ACM. pp. 145-155.
Keywords: *Menus, system control, augmented reality, 3D user interfaces*
Annotations: The authors explore three kinds of widgets, which were 2D windows overlapped on physical world in their augmented environment application: surround-fixed windows, display-fixed windows, world-fixed windows. The authors discuss widgets placement and frame rate issues. Although the paper primarily deals with the aug-

mented reality applications, conclusions and results can be used in designing any 3D interface.

52. Fisher, S., McGreevy, M., Humphries, J., Robinett, W., Virtual Environment Display System. *Proceedings of Workshop on Interactive 3D Graphics*. 1986. ACM.
Keywords: *display, two-handed interaction*
Annotations: An excellent piece of early virtual reality research. NASA Telepresence research. Not mentioned in the text, but clearly the authors envisioned two-handed manipulation (along with voice input and 3D localized sound).

53. Foley, D., Wallace, V., Chan, V., The human factors of computer graphics interaction techniques. *IEEE Computer Graphics & Applications*, 1984(4): pp. 13-48.
Annotations: This is one of the most fundamental papers on interaction techniques for graphical user interfaces. This paper was probably one of the first attempts to break down complex interaction sequences into several basic interaction tasks and propose that each elementary interaction task is accomplished by the means of the certain interaction techniques. The paper surveys many of the interaction techniques and while most of them are 2D some 3D techniques are also briefly discussed. Parts of this paper have been included in the well known textbook on computer graphics by Foley, van Dam and others.

54. Forsberg, A., Herndon, K., Zeleznik, R., Aperture based selection for immersive virtual environment. *Proceedings of UIST'96*. 1996. ACM. pp. 95-96.
Keywords: *VR, virtual reality, 3D interaction techniques, direct manipulation, selection, 3D interaction, pointing*
Annotations: Describes an interaction technique for selecting objects in immersive VR. The technique is an extension of the flash-light technique (see Liang, 1994): it allows to interactively control the size of the conic selection volume which, in turn, allows easier disambiguation of target objects.

55. Forsberg, A., LaViola, J., Markosian, M., Zeleznik, R., Seamless Interaction In Virtual Reality. *IEEE Computer Graphics and Applications*, 1997. 17(6): pp. 6-9.
Keywords: *seamless integration, ErgoSketch, 2D/3D input, VR, responsive workbench, interaction techniques, 3D interfaces*
Annotations: This paper talks about the importance of seamlessly combining 2D and 3D interaction techniques and discusses when each interaction metaphor is appropriate in the context of 3D modeling.

56. Forsberg, A., LaViola, J., Zeleznik, R., ErgoDesk: A Framework For Two and Three Dimensional Interaction at the ActiveDesk. *Proceedings of Second International Immersive Projection Technology Workshop*. 1998.
Keywords: *ActiveDesk, sketch, 3D interaction, 3d modeling, two-handed input*
Annotations: This paper presents a hardware and software framework for combining 2D and 3D interaction in projection-based virtual reality.

57. Froehlich, B., Plate, J., The Cubic Mouse, A New Device for Three-Dimensional Input. *Proceedings of CHI*. 2000. ACM.
Keywords: *Input device, props, visualisation, interaction, cutting and slicing planes*
Annotations: The authors describe a new device for three-dimensional input. The device is built up from a cube-shaped box with a tracker, and three rods running through the axes of the cube. The device allows very fine interaction with several described applications, and shows good evaluation results from a performed user study.

58. Galyean, T., Guided navigation of virtual environments. *Proceedings of Symposium on Interactive 3D Graphics*. 1995. ACM. pp. 103-104.
Keywords: *VR, navigation, 3D interface, viewpoint control*
Annotations: Interesting technique for navigation in VR where the user is guided along the path in the environment and yet has some degree of freedom to explore it. The technique is based on the "The River Analogy" metaphor, where the user is like a boat floating down a river and pulled by the stream and just lie a bout he or she can diverge from the strait path to look around. The technique can be very useful in designing interfaces for narrative, story telling VR environments.

59. Gobbetti, E., Balaguer, J., VB2 : A Framework for Interaction in Synthetic Worlds. *Proceedings of UIST*. 1993. ACM. pp. 167-178.
Keywords: *User interface design, 3D virtual tools, gestural input, 3D user interaction*
Annotations: The paper describes the VB2 architecture for the construction of three-dimensional interactive applications. The authors deal with virtual tools, constraints, gestural input and direct manipulation. An example application domain, animation, is used to illuminate the topics.

60. Goble, J., Hinckley, K., Pausch, R., Snell, J., Kassell, N., Two-Handed Spatial Interface Tools for Neurosurgical Planning. *Computer*, 1995. 28(7): pp. 20-26.
Keywords: *props, 3D input, domain-specific interaction, two-handed interaction*
Annotations: Presents the Netra system, important for its use of real-world props to aid in 3D manipulation, and the concept of clutching during 3D manipulation.

61. Goesele, M., Stuerzlinger, W., Semantic Constraints for Scene Manipulation. *Proceedings of Spring Conference in Computer Graphics '99*. 1999. pp. 140-146.
Keywords: *Semantics, manipulation, 3D user interface*
Annotations: The system uses semantic/pragmatic constraints to simplify the 3D user interface for a Virtual Reality system. It builds upon Bukowski and Sequin's work.

62. Grissom, S., Perlman, G., StEP(3D): A standardized evaluation plan for three-dimensional interaction techniques. *International Journal of Human-Computer Studies*, 1995. 43(1): pp. 15-41.
Keywords: *testbed, 3D user interface, manipulation, interaction techniques*
Annotations: The testbed for evaluation of 3D interaction techniques. For another example of experimental testbed see [Poupyrev, et al. 1997]

63. Hand, C., A Survey of 3D Interaction Techniques. *Computer Graphics Forum*, 1997. 16(5): pp. 269-281.
Keywords: *VR, 3D, survey, interaction technique, manipulation, navigation, viewpoint control, feedback, widgets*
Annotations: Interesting and pretty extensive survey of interaction techniques for desktop and immersive VR and issues related to their development.

64. Harmon, R., Patterson, W., Ribarsky, W., Bolter, J., The virtual annotation system. *Proceedings of VRAIS'96*. 1996. IEEE. pp. 239-245.
Keywords: *virtual annotation system, annotation tools, voice annotations, icon, architectural walkthrough, virtual reality, 3D interaction*
Annotations: 1. The paper presents a set of voice annotation tools that can be placed in a variety of VR applications. These tools offer a set of capabilities for inserting, iconizing, playing back and organizing voice annotations in a virtual space. 2. See also Verlinden, Bolter, et al. 1993 where this idea was first introduced.

65. Harris, L., Jenkin, M., Zikovitz, D., Vestibular cues and virtual environments: choosing the magnitude of the vestibular cue. *Proceedings of VR'99*. 1999. IEEE. pp. 229-236.
Keywords: *Vestibular cues, receptors, real-motion cues, cart, perception, VR*
Annotations: This article reports the correlation between visual input and real-motion cues. Reported is, that a virtual reality system designer should supply four times as much visual motion as vestibular motion to obtain accuracy during passive motion.

66. Henry, D., Furness, T., Spatial perception in virtual environments: evaluating an architectural application. *Proceedings of VRAIS'93*. 1993. IEEE. pp. 33-40.
Keywords: *spatial representation, perception, wayfinding, architectural space, VR, navigation*
Annotations: 1. Early report on factors influencing the effectiveness of representation of architectural space within virtual environments. Henry reports distance estimation and orientation biases between virtual environments and real world environments. 2. The article compared how users perceive real and virtual environments. The author designed a virtual environment which replicates exactly a physical environment and aligned them "on top" of each other. He founded and described differences in user perception of both environments and suggest reasons while this differences occur(e.g. limited vertical field of view of HMD)

67. Herndon, K., Meyer, T., 3D widgets for exploratory scientific visualization. *Proceedings of UIST'94*. 1994. ACM. pp. 69-70.
Keywords: *Widgets, system control, interactive shadows*
Annotations: The paper describes several 3D widgets for scientific data exploration and further exploration of previous work on interactive shadows. The authors also describe several design issues related to geometry, dimensionality and user feedback.

68. Herndon, K., van Dam, A., Gleicher, M., The challenges of 3D interaction: a CHI'94 workshop. *SIGCHI Bulletin*, 1994. 26(4): pp. 36-43.
Keywords: *3D interaction, survey*
Annotations: 1. A report on a CHI workshop listing most of the important challenges and research direction in 3D interaction. 2. Summarizes discussions held at the CHI'94 Workshop on 3D interaction. Covers a wide range of topics, including applications of 3D graphics, psychology and perception issues, state of the art work, and future research directions. Includes an excellent bibliography.

69. Herndon, K.P., Zeleznik, R.C., Robbins, D.C., Conner, D.B., Snibbe, S.S., *et al.*, Interactive shadows. *Proceedings of UIST'92*. 1992. ACM. pp. 1-6.
Keywords: *interactive shadows, spatial relationships, 3D interaction techniques, manipulation techniques, 3D widgets, shadow widgets, 3D user interfaces, desktop 3D interaction*
Annotations: Paper present a set of 3D widgets called "shadows" that provide perceptual cues about the spatial relationships between objects, and also provide a direct manipulation interface to position objects. Unlike some other 3D widgets, they do not obscure the objects they control.

70. Hinckley, K., Pausch, R., Goble, J., Kassell, N., A survey of design issues in spatial input. *Proceedings of UIST '94*. 1994. ACM. pp. 213-22.
Keywords: *spatial input, design issues survey, 3D interaction, 3D interfaces, virtual environment, VR, two-handed interaction, feedback, physical constraints, head tracking, interaction techniques.*
Annotations: 1. A survey of design issues for developing effective free-space three-dimensional (3D) user interfaces based upon authors previous work in 3D interaction, our experience in developing free-space interfaces, and informal observations of test users. Can serve as a guide to researchers or systems builders. 2. A practical and useful set of principles to follow when 3D input is given to a computer system.

71. Hinckley, K., Pausch, R., Proffitt, D., Patten, J., Kassell, N., Cooperative bimanual action. *Proceedings of CHI'97*. 1997. ACM. pp. 27-34.
Keywords: *manipulation, 3D interfaces, bi-manual interaction, two-handed interaction, experimental evaluation*
Annotations: Paper presents experiments on two-handed manipulation. The paper concentrates on division of labor between two hands when performing a single task, i.e. cooperative two-handed manipulation. Experiments suggest that left hand defines a spatial frame of reference for the right hand for complex manipulation actions. The contribution of hands is, therefore, asymmetric.

72. Hinckley, K., Tullio, J., Pausch, R., Profitt, D., Kassell, N., Usability Analysis of 3D Rotation Techniques. *Proceedings of UIST'97*. 1997. pp. 1-10.
Keywords: *Arcball, Virtual Sphere, 6DOF input devices, usability, manipulation, 3D interaction technique, interactive rotation, experimental studies*
Annotations: 1. Good report on user study of 3D rotation using mouse-driven Virtual Sphere and ARCBALL techniques, as well as 6DOF input devices. 2. The main result of this paper is that 6DOF devices do allow for better user performance in rotation task without sacrificing accuracy. Physical form of device has also been investigated, however, no performance difference have been found for devices with different shapes. The shape of device, however, did influence the user acceptance and subjective rating of device.

73. Hinkley, K., Pausch, R., Goble, J., Kassell, N., Passive Real-World Interface Props for Neurosurgical Visualization. *Proceedings of CHI'94*. 1994. ACM. pp. 452-458.
Keywords: *3D interaction, gesture input, two-handed interaction, haptic input, neurosurgery, visualization, 3D interfaces*
Annotations: Classical article on usage of props. Excellent review of possibilities and problems

74. Hoffman, H., Physically touching virtual objects using tactile augmentation enhances the realism of virtual envi-

ronments. *Proceedings of VRAIS'98*. 1998. IEEE. pp. 59-63.
Keywords: *VR, virtual reality, realism, haptic and tactile feedback, physical props, experimental study*
Annotations: Reports experimental study which empirically demonstrated that adding tactile augmentation, or simply props, can increase realism of the virtual environment. Argues a value of adding props in 3D interface design for VR. See also [Hinckley, 1994]

75. Houde, S., Iterative Design of an Interface for Easy 3-D Direct Manipulation. *Proceedings of CHI'92*. 1992. ACM. pp. 135-142.
Keywords: *3-D manipulation, bounding box, direct manipulation, hand gestures, handle box, iterative design, narrative handles, space planning*
Annotations: Describes a system with handles on object for 3D manipulation; hand-shaped cursors suggest type of manipulation being performed. The system must switch modes when going between translations and rotations.

76. Howard, I., Spatial vision within egocentric and exocentric frames of reference. In *Pictorial communication in virtual and real environments*, S. Ellis, *et al*., Editors. 1991, Tayler and Francis Ltd.: London. pp. 338-357.
Keywords: *frames of reference, perception, wayfinding, vection, VR*
Annotations: An excellent survey on how egocentric and exocentric reference frames are built, and how they function. With examples gained from tests, Howard also illuminates several related factors like vection.

77. Hultquits, J., A Virtual Trackball. In *Graphics Gems I*. 1990, Academic Press. pp. 462-463.
Keywords: *3D rotations, desktop interface, mouse, trackball*
Annotations: Technique to control 3D rotations using a mouse. Mouse movements, sampled repeatedly, are used to compute instantaneous rotation axis of the 3D object. See also [Shoemake, 92, Chen, 88, Hinckley'97]

78. Ingram, R., Bowers, J., Benford, S., Building virtual cities: applying urban planning principles to the design of virtual environments. *Proceedings of VRST'96*. 1996. ACM.
Keywords: *wayfinding, structuring, perception, Lynch, urban planning, VR*
Annotations: An interesting article on how Lynch' Image of the City can be applied for the design of virtual environments.

79. Iwata, H., Fujii, T., Virtual Perambulator: A Novel Interface Device for Locomotion in Virtual Environment. *Proceedings of VRAIS'96*. 1996. IEEE. pp. 60-65.
Keywords: *travel, locomotion, natural interaction, walking technique, 3D interaction, VR, virtual reality*
Annotations: One of the many systems that attempts to simulate walking by having the user walk in place. Requires trackers only, and no expensive hardware

80. Jacob, R., Deligiannidis, L., Morrison, A Software Model and Specification Language for Non-WIMP User Interfaces. *Transactions on Computer-Human Interaction*, 1999. 6(1): pp. 1-46.
Keywords: *3D user interfaces, inteaction techniques, non-WIMP interface, specification language*
Annotations: A software model and language for describing and programming interaction in non-WIMP user interfaces is presented. The model combines a data-flow or constraint-like component for the continuous relationships with an event-based component for discrete interactions, which can enable or disable individual continuous relationships. The description of the PMIW user interface management system demonstrates the approach. The main goal is to provide a model and language that captures the formal structure of non-WIMP interactions in the way that various previous techniques have captured command-based, textual and event-based styles.

81. Jacob, R., Sibert, L., The Perceptual Structure of Multidimensional Input Device Selection. *Proceedings of CHI'92*. 1992. ACM. pp. 211-218.
Keywords: *polhemus tracker, gesture input, input devices, integrality, interaction techniques, perceptual space, separability*
Annotations: This study addresses the question: "What is a three-dimensional tracker good for?" The authors hypothesize that "the structure of the perceptual space of an interaction task should mirror that of the control space of its input device." Thus, a 3D tracker would be good for a task which involves the selection of three related ("integral") dimensions, but would be less effective for unrelated ("separable") dimensions. The study had users perform two interaction tasks with both a Polhemus and a mouse. One task involved setting three integral parameters (x, y location and size of a rectangle), while the other involved separable parameters (x, y location and color of a rectangle). The data collected suggested that matching the integrality/separability of the device to the task yields the best user performance. Neither the Polhemus or the mouse was uniformly superior; each device performed best when it was correctly mapped to "the perceptual structure of the task space".

82. Jacoby, R., Ellis, S., Using Virtual Menus in a Virtual Environment. *Proceedings of Visual Data Interpretation, 1668*. 1992. SPIE. pp. 39-48.
Keywords: *3D menus, commands, 3D interaction*
Annotations: One of the first systems to use virtual pull-down menus in a VE

83. Kaufman, A., Yagel, R., Tools for Interaction in Three Dimensions. *Proceedings of 3rd International Conference on Human-Computer Interaction*. 1989. pp. 468-475.
Keywords: *display system, jack, projection methods, desktop 3D user interface*
Annotations: This paper contains the most comprehensive description of the 3D user interface for Kaufman's CUBE workstation. Cube has viewing windows which employ a "combination look" for object rendering: drawings are superimposed on shaded images to capitalize on the advantages of each type of look. A separate window ("World Space") allows the user to specify the eye point, the direction of projection, the projection surface, the light sources (3), etc. The world view can be merged with the view window on sufficiently fast machines. A "full jack" or a jack with shadows on each wall is used to relate position information. The paper advocates having anchors in each objects to help with positioning; this is mostly useful in geometric objects which have been created in the environment (to define volumes of interest or surgical implants). A gravity mechanism is used to assist motion during object picking and parameter specification.

84. Kessler, G., A Framework for Interactors in Immersive Virtual Environments. *Proceedings of VR'99*. 1999. IEEE. pp. 190-197.

Keywords: *Interaction techniques, framework, user interface*
Annotations: SVIFT, the Simple Virtual Interactor Framework and Toolkit, is presented to meet the interaction needs of immersive VE applications. SVIFT allows for the design and implementation of various interaction techniques that can be easily incorporated into many VE applications and combined with other interaction techniques. Differences between desktop and immersive environment interaction are also discussed.

85. Koller, D., Mine, M., Hudson, S., Head-tracked orbital viewing: An interaction technique for immersive Virtual Environments. *Proceedings of UIST'96*. 1996. ACM. pp. 81-82.
Keywords: *object viewing, head-based manipulation, viewpoint control, 3D interaction, virtual reality*
Annotations: This technique maps the user's head motion to the view the user receives of a virtual object - look up to see the bottom of the object, look down to see the top and etc.

86. Krueger, M., Gionfriddo, T., Hinrichsen, K., VIDEOPLACE - An Artificial Reality. *Proceedings of CHI'85*. 1985. ACM. pp. 35-40.
Keywords: *artificial reality, video-based tracking, gestures, projection, gesture inout*
Annotations: In VIDEOPLACE, one of the most compelling examples is using both hands to edit a B-spline curve: you can use index finger & thumb of each hand to simultaneously manipulate 4 control points at once. Even though the system is over 10 years old, in many ways it offered much richer interaction than present day technologies.

87. Latta, J.N., Oberg, D.J., A conceptual virtual reality model. *IEEE Computer Graphics & Applications*, 1994. 14(1): pp. 23-29.
Keywords: *3D interaction, VR, virtual reality, theory, conceptual models, perception, sensation.*
Annotations: Presents a conceptual model of VR. First, the definition of VR is suggested as a user interface to human perceptual and muscle system (listed) which objective is to place the user in an environment that is not normally or easily experienced. Several views of the VR systems are presented after that: human view and technical view. The human view is described basically from the point of system effectors, i.e what user can feel, and system sensors, i.e. what user actions can be captured by the system. The technical view is a usual diagram of various components of the VR systems.

88. LaViola, J., Zeleznik, R., Flex and Pinch: A Case Study of Whole-Hand Input Design for Virtual Environment Interaction. *Proceedings of International Conference on Computer Graphics and Imaging'99*. 1999. IASTED. pp. 221-225.
Keywords: *3D graphics applications, conductive cloth, flex and pinch input, multimodal interaction, 3D user interfaces, VR, gesture and glove input, interaction techniques*
Annotations: This paper describes a hybrid input device that combines the continuous bend sensors from a data glove and the discrete contact sensors from the Fakespace Pinch glove. It describes improvements to a number of existing 3D interaction techniques.

89. LaViola, J.J., A survey of hand postures and gesture recognition techniques and technology. Brown University, Providence: *Technical Report CS-99-11*. 1999.
Keywords: *Glove interaction, gestures, postures, recognition techniques*
Annotations: An overview of gesture interaction technology for multimodal interaction with focus on VR and 3D UI. The survey reviews various gesture capturing and recognition technologies.

90. LeBlanc, A., Kalra P, Magnenat-Thalmann, N., Thalmann, D., Sculpting with the "Ball and Mouse" Metaphor. *Proceedings of Graphics Interface '91*. 1991. pp. 152-159.
Keywords: *two-handed interaction, modeling, spacemouse, 3D user interfaces, manipulation, desktop*
Annotations: Describes a two-handed 3D interface based on orienting object with spaceball in left hand (rotations only) and grabbing it with the mouse

91. Liang, J., Green, M., JDCAD: A highly interactive 3D modeling system. *Computer & Graphics*, 1994. 4(18): pp. 499-506.
Keywords: *geometric modeling, 3D interfaces, constraints, input devices. selection techniques.*
Annotations: 1. Good article on constrained (1DOF) menu systems and bat usage 2. The flash light technique that uses conic selection volume for 3D object selection has been introduced here. 3. Describes a Polhemus-based CAD system. The user hold the polhemus in front of the monitor and casts rays into the scene, rather than picking directly based on the position of the polhemus. This provides a nice metaphor for working at increased scale -- the user can zoom in on an object to see detail; since everything is done relative to the image on the monitor, a hand motion in real space now results in a small-scale motion in virtual space. A lot of interesting ideas.

92. Lindeman, R., Sibert, J., Hahn, J., Hand-held Windows: Towards Effective 2D Interaction in Immersive Virtual Environments. *Proceedings of VR'99*. 1999. IEEE. pp. 205-212.
Keywords: *2D widgets, pen and tablet interaction, two-handed interaction*
Annotations: The authors describe a testbed taking advantage of bimanual interaction, proprioception, and passive-haptic feedback to perform more precise manipulations in immersive virtual environments using 2D interaction techniques. They use a window registered with a tracked, physical surface to provide support for precise manipulation of interface widgets displayed in the virtual environment.

93. Liu, A., Stark, L., Hirose, M., Interaction of Visual Depth Cues and Viewing Parameters During Simulation Telemanipulation. *Proceedings of IEEE International Conference on Robotics and Automation*. 1991. pp. 2286-2291.
Keywords: *Telemanipulation, visual cues and parameters*
Annotations: User study. Tests the effectiveness of head motion parallax, but the motion was not under user control: the view simply oscillated under machine control. "Our experimental results do not provide strong evidence that relative depth cues affected tasks that required absolute depth information. The object rotation cue did not enhance task performance because it only provided information about the object's three dimensionality. Pseudo-head motion parallax as we implemented it, also did not no enhance performance, but if implemented under operator

control, it might prove to be a more effective cue. The frustrum angle decreased completion time but had no effect on error."

94. Mackinlay, J., C., S., Robertson, G., Rapid controlled movement through a virtual 3D workspace. *Proceedings of SIGGRAPH'90*. 1990. ACM. pp. 171 - 176.
Keywords: *transitional motion, automated travel, interaction technique, 3D interaction*
Annotations: This technique uses the "slow-in, slow-out" movement favoured by animators in moving a user's viewpoint through a 3D space.

95. Mapes, D., Moshell, J., A Two-Handed Interface for Object Manipulation in Virtual Environments*. Presence: Teleoperators and Virtual Environments*, 1995. 4(4): pp. 403-416.
Keywords: *virtual workbench, pinch glove interaction, 3D manipulation, two-handed interaction, gestures, multimodal input, virtual reality, 3D interfaces*
Annotations: 1. This system, which evolved into an actual Multigen product, has interesting 2-handed techniques for viewpoint motion and object manipulation. 2. Polyshop system which has become SmartScenes product by Multigen.

96. Massimo, M., Sheridan, T., Roseborough, J., One Handed Tracking in Six Degrees of Freedom. *Proceedings of International Conference on Systems, Man and Cybernetics*. 1989. IEEE. pp. 498-503.
Keywords: *Tracking, spaceball, 6DOF, 3D user interfaces, experiments, user studies, devices*
Annotations: This article reports on user experiments for controlling 1, 3, and 6 degrees of freedom at a time for "pursuit" tracking tasks with a sensor ball (apparently identical to a spaceball) as an input device. It also tests the usage of velocity control vs. acceleration control. In all cases (1, 3, 6 DoF) z translations were the most difficult to control, and velocity input yielded better control than acceleration input. The use of shadows as depth cues did not help z translations.

97. McKenna, M., Interactive Viewpoint Control and Three-Dimensional Operations. *Proceedings of Symposium on Interactive 3D Graphics*. 1992. ACM. pp. 53-56.
Keywords: *Fish tank VR, tracking, viewpoint control, head tracking, desktop VR, 3D interfaces*
Annotations: Describes a "fish tank VR" system which changes the image on a standard 2D monitor based on head position. This allows perspective and motion parallax (monocular depth cues) without a HMD. An extension of this technique also tracks the monitor, allowing additional freedom (e.g. translation/rotation of the monitor). A Polhemus sensor is used to track the head; a stereoscopic version is described but not implemented.

98. McMillan, G., Eggelston, R., Anderson, T., Nonconventional controls. In *Handbook of human factors and ergonomics*, G. Salvendy, Editor. 1997, John Wiley and Sons: New York. pp. 729-771.
Keywords: *System control, speech, gestures, tracking*
Annotations: An excellent chapter on nonconventional control methods, like gestures, speech and gaze tracking. The authors also supply several user feedback guidelines. The material in this chapter would be especially beneficial to everybody who want to use these less conventional techniques in designing multimodal 3D user interfaces.

99. Mine, M., Virtual environment interaction techniques. UNC Chapel Hill CS Dept.: *Technical Report TR95-018*. 1995.
Keywords: *3D interaction. 3D user interface. 3D widgets. direct manipulation. interaction techniques. navigating. user interface. viewpoint control. VR.*
Annotations: 1. An overview of many of the most important early techniques for travel, selection, and manipulation in immersive VEs. 2. Good review, and must read for anybody who works with 3D interaction. However, since it was done in 1995 many newest and interesting ideas and techniques are not there.

100. Mine, M., ISAAC: A Meta-CAD System for Virtual Environments. *Computer-Aided Design*, 1997. 29(8): pp. 547-553.
Keywords: *immersive design, constraints, 3D manipulation, virtual menus*
Annotations: A system for describing the layout of 3D objects immersively. Uses several novel and well-constrained interaction techniques.

101. Mine, M., Brooks, F., Sequin, C., Moving objects in space: exploiting proprioception in virtual-environment interaction. *Proceedings of SIGGRAPH'97*. 1997. ACM. pp. 19-26.
Keywords: *3D interfaces, virtual reality, interaction techniques, manipulation, navigation, proprioception , 3D widgets, guidelines*
Annotations: 1. Thorough analysis of the effects of proprioception on user interface techniques. 2. Discuss design of a interaction techniques for manipulation, navigation and other tasks. Introduces several new techniques and discuss their design implications.

102. Osborn, J., Agogino, A., An Interface for Interactive Spatial Reasoning and Visualization. *Proceedings of Human Factors in Computing Systems Conference*. 1992. HFS. pp. 75-82.
Keywords: *Spatial reasoning, cutting planes, desktop 3D, visualization*
Annotations: This paper describes a mouse-based user interface for spatial reasoning and visualization. The interface includes the ability to orient an object and select arbitrary cutting planes; this portion of the interface is discussed in considerable detail. The basic interaction metaphor is that of manipulating the object in a "pool of water," the surface of which forms the cutting plane. The user rotates the model into the desired orientation, and then adjusts the depth of the "pool" to select the depth of the cut.

103. Ostby, E., Describing Free-Form 3D Surfaces for Animation. *Proceedings of Workshop on Interactive 3D Graphics*. 1986. ACM. pp. 251-258.
Keywords: *Tracking, freeform modeling, 3D user interfaces, surface deformation.*
Annotations: The author investigates several uses of the Polhemus tracker for specifying the surfaces of 3D objects. Uses included: * Probe: Sample probe at user signal; sample at many points in space to define an object. It was hard to locate a 3D point on a two-dimensional display. The author found that using the device in combination with a real object helped solve this problem. 1.) Pencil: Draw lines in space, or trace a grid over the surface of an actual object. Use least-squares to fit a patch 2.) Camera for viewing: Works well and feels natural 3.) Tool for deforming the surface of existing objects: Use relative motion to deform. Relative motion is easier to control. Problems with the Polhemus tracker included: * Lack of a tip

switch -- need equivalent of mouse click * Drawing free-hand in open space is hard: no friction to facilitate control * Locating points in space with only 2D display

104. Pausch, R., Burnette, T., Brockway, D., Weiblen, M., Navigation and Locomotion in Virtual Worlds via Flight into Hand-Held Miniatures. *Proceedings of SIGGRAPH'95, Technical Sketches*. 1995. ACM. pp. 399-400.
Keywords: *multi-scale travel, viewpoint manipulation, interaction technique, virtual reality*
Annotations: This short paper describes a technique for moving one's viewpoint by moving a small icon representing yourself, and then flying into the scale model to take that new position.

105. Pausch, R., Burnette, T., Brockway, D., Weiblen, M., Navigation and Locomotion in Virtual Worlds via Flight into Hand-Held Miniatures. *Proceedings of SIGGRAPH'95*. 1995. ACM. pp. 399-400.
Keywords: *3D interfaces, navigation, locomotion, WIM, VR*
Annotations: This paper describes the use of a World-in-Miniature (WIM) as a navigation and locomotion device in immersive virtual environments. When the user moves an iconic representation of himself in the WIM he moves (flies) in the virtual environment. See also [Stoackley, et al. 1995]

106. Pausch, R., Crea, T., Conway, M., A Literature Survey for Virtual Environments: Military Flight Simulator Visual Systems and Simulator Sickness. 1995. 1(3).
Keywords: *motion sickness, VR, flight simulators, military, survey*
Annotations: Gives a quick overview of simulator research along with lots of references from military research which are very difficult to find in the academic literature. The references are annotated.

107. Pausch, R., Snoddy, J., Taylor, R., Watson, S., Haseltine, E., Disney's Aladdin: first steps toward storytelling in virtual reality. *Proceedings of SIGGRAPH'96*. 1996. ACM.
Keywords: *virtual reality, story telling, evaluation, navigation, design, art, presence, immersion, VR entertainment*
Annotations: The paper describes experience of developing and results of evaluation a virtual reality entertainment attraction "Aladdin" installed in Disney park. Results of observation and interview with approximately 45000 visitors over 14 months are reported. Many important interface issues related to design of VR entertaining systems are reported here.

108. Pierce, J., Conway, M., Van Dantzich, M., Robertson, G., Toolspaces and Glances. *Proceedings of Symposium on Interactive 3D Graphics*. 1999. pp. 163-168.
Keywords: *Gestural interaction, viewpoint control, tools*
Annotations: This paper presents "two go greats that go great together": glances, a lightweight approach to providing different viewpoints, and toolspaces, a way of using the space around the user for different purposes. Together these techniques allow designers to, for example, create a 3D storage space that can be accessed with a simple gesture for users of desktop 3D worlds.

109. Pierce, J., Forsberg, A., Conway, M., Hong, S., Zeleznik, R., *et al.*, Image plane interaction techniques in 3D immersive environments. *Proceedings of Symposium on Interactive 3D Graphics*. 1997. ACM. pp. 39-43.
Keywords: *3D, manipulation, selection, interaction technique, VR*
Annotations: An interesting approach to the problem of remote object manipulation in immersive VEs.

110. Pierce, J., Stearns, B., Pausch, R., Two Handed Manipulation of Voodoo Dolls in Virtual Environments. *Proceedings of Symposium on Interactive 3D Graphics*. 1999. pp. 141-145.
Keywords: *Image plane techniques, selection, voodoo dolls, two handed interaction*
Annotations: The Voodoo Dolls technique leverages some of Pierce's earlier work on image plane techniques to provide a method of fluidly manipulating and positioning objects in a scene. The technique draws on how users work with their hands, where the non-dominant hand defines the frame of reference that the dominant hand works in.

111. Poston, T., Serra, L., Dextrous Virtual Work. *Communications of the ACM*, 1996. 39(5): pp. 37-45.
Keywords: *application, medicine, 3D interaction, two-handed manipulation, visualization*
Annotations: "A system for visualizing and manipulating medial images is detailed, with emphasis on interaction techniques." Uses a mirrored set up (opaque mirror, not half-silvered) with stereoscopic display. The mirror is up relatively near your face, leaving a large work volume for the hands behind the mirror. Not a major point of the paper, but the system employs two-handed interaction: rotation of a brain image with the left hand and fine manipulation with the right hand, using a physical tool handle that has multiple virtual effectors.

112. Poupyrev, I., Billinghurst, M., Weghorst, S., Ichikawa, T., Go-Go Interaction Technique: Non-Linear Mapping for Direct Manipulation in VR. *Proceedings of UIST'96*. 1996. ACM. pp. 79-80.
Keywords: *3D interaction, 3D user interface, direct manipulation, interaction techniques, virtual reality, non-linear C-D gain.*
Annotations: Interaction technique for manipulation in virtual environment. The technique uses non-linear control display gain to extend the user reach and manipulate both objects within the user reach as well as those at a distance.

113. Poupyrev, I., Tomokazu, N., Weghorst, S., Virtual Notepad: handwriting in immersive VR. *Proceedings of VRAIS'98*. 1998. IEEE. pp. 126-132.
Keywords: *virtual environment, interaction technique, handwriting, text input, annotation, pen input, 2D input in 3D, multimodal interaction,*
Annotations: The Virtual Notepad is a set of interface tools that uses handwriting to allow the user to write, draw and annotate documents while immersed in virtual environments. Using handwriting recognition with Virtual Notepad allows for text input from within virtual environments.

114. Poupyrev, I., Weghorst, S., Billinghurst, M., Ichikawa, T., A framework and testbed for studying manipulation techniques for immersive VR. *Proceedings of VRST'97*. 1997. ACM. pp. 21-28.
Keywords: *VR, manipulation, 3D user interfaces, testbed, experimental evaluation, user study, taxonomy, design, task analysis*

Annotations: Testbed for experimental evaluation of 3D interaction techniques in virtual environments: Virtual Reality Manipulation Assessment Testbed (VRMAT). The VRMAT provides a detailed break-down of the 3D manipulation task, discusses main variables affecting user manipulation performance and attempts to introduce user-centered metrics for describing spatial characteristics of the virtual environments. The main idea behind introducing user-centered metrics, i.e. metrics based on the user physical parameters, such as arm length, rather then on the physical parameters of the real world, such as in case of meters, is to be able to describe the spatial characteristics of the environment independently from the system implementation and from the point of view of the user

115. Poupyrev, I., Weghorst, S., Billinghurst, M., Ichikawa, T., Egocentric object manipulation in virtual environments: empirical evaluation of interaction techniques. *Computer Graphics Forum, EUROGRAPHICS'98 issue*, 1998. 17(3): pp. 41-52.
Keywords: *interaction techniques, taxonomy, classification, user studies, experiments, manipulation, pointing and grabbing, metaphor*
Annotations: Describes the first formal experiments to evaluate interaction techniques for object selection and manipulation in immersive VEs. The experiments were conducted within the taxonomy of interaction techniques which is also presented in the paper.

116. Poupyrev, I., Weghorst, S., Fels, S., Non-isomorphic 3D rotational interaction techniques. *Proceedings of CHI2000*. 2000. ACM.
Keywords: *3D interaction, VR, object manipulation, 3D input devices, device form factor, interaction techniques, object rotations, user studies*
Annotations: This paper demonstrates how to design 3D rotational interaction techniques that amplify rotations of the input device in manipulation task. It also demonstrates their properties and shows how these techniques can be used to build effective spatial 3D user interfaces. First, a mathematical framework allowing to design 3D rotational mappings and techniques, is designed. Then, authors investigate their usability properties. Finally, the experimental results are reported. The results suggest that non-isomorphic rotational mappings can be effective in building 3D manipulation dialogues, in reported experiments they allowed subjects to accomplish experimental tasks 13% faster without a statistically detectable loss in accuracy.

117. Raab, F., Blood, E., Steiner, T., Jones, H., Magnetic Position and Orientation Tracking System. *IEEE Transaction on Aerospace and Electronic Systems*, 1979. AES-15(5): pp. 709-717.
Keywords: *3D input device, magnetic tracker, Polhemus, position and orientation tracking*
Annotations: Describes the theoretical underpinnings of the Polhemus tracker. Also talks about application considerations, source/sensor imperfections, and the problems caused by nearby metallic structure. Rule of thumb for metal: "An object whose distance from the source is at least twice the distance separating the source and sensor produces a scattered field whose magnitude is 1 percent or less of the magnitude of the desired field.

118. Regenbrecht, H., Schubert, T., Friedmann, F., Measuring the Sense of Presence and its Relations to Fear of Heights in Virtual Environments. *International Journal of Human-Computer Interaction*, 1998. 10(3): pp. 233-250.
Keywords: *presence, measurement, fear of heights, VR*
Annotations: Good article dealing with measuring presence, the thereby involved factors which cause presence, and the coupling to fear of heights tests.

119. Robbins, D., Practical 3D user interface design. SIGGRAPH'96 Course Notes: *Technical Report 31*. 1996.
Keywords: *3D user interfaces, interface design, desktop 3D interfaces*
Annotations: These notes for tutorial presented at the SIGGRAPH'96 take the reader through the process of designing 3D interface for a simple application: Theater Lightning Design. The application and 3D interface are being developed for the conventional desktop 3D environment. Tutorial discusses many ideas, rules and tricks in designing effective 3D interaction.

120. Robertson, G., Card, S., Mackinlay, J., The Cognitive Coprocessor Architecture for Interactive User Interfaces. *Proceedings of UIST'89*. 1989. ACM. pp. 10-18.
Keywords: *3D interfaces, software tool, software architecture, agent, animation,*
Annotations: Describes a software architecture which is appropriate for the real-time demands of 3D interactive applications, including animation. There are two problems: * Multiple Agent Problem: UI must match "time constants" of human and computer. The architecture must "manage the interactions of multiple asynchronous agents that can interrupt and redirect each other's work." * Animation Problem: Interactive animation can shift the user's task from cognitive to perceptual, which fees cognitive ability. Animation of motion allows a continuity of perception; discontinuous motion requires reassimilation of the new display. The paper advocates a three agent model: User, user discourse machine, and task machine. The cognitive coprocessor is a UI architecture which supports this model, plus "intelligent" agents and smooth animation. The animation loop (on the user discourse machine) is the basic control mechanism. It maintains a task queue (pending computations from agents), a display queue (pending instructions from against for how the screen should be painted on the next animation loop cycle), and a governor (keeps track of time & allows for adjustments to animations to keep them smooth). The paper goes on to describe a "3D Rooms" example based on this architecture.

121. Ruddle, R., Payne, S., Jones, D., Navigating large-scale "Desk-Top" virtual buildings: Effects of orientation aids and familiarity. *Presence: Teleoperators and Virtual Environments*, 1998. 7(2): pp. 179-192.
Keywords: *Wayfinding, spatial orientation, cues, aids, desktop VR*
Annotations: Excellent article dealing with how participants deal with spatial knowledge when navigating in virtual worlds using a desktop VR system. Article describes 2 experiments which deal with direction and distance estimations. Authors describe influences of aids (like a compass) on the accuracy of spatial knowledge.

122. Rygol, M., Dorbie, A., Worden, A., Ghee, S., Grimsdale, C., *et al.*, Tools and metaphors for user interaction in virtual environments. In *Virtual Reality Applications*, R.A. Earnshaw, J.A. Vince, and H. Jones, Editors. 1995, Academic Press. pp. 149-161.

Keywords: *3D interaction, interface toolkit, 3D user interface, 3D widgets, direct manipulation, VR tools, metaphor*
Annotations: Describes 3D user interface toolkit that has been implemented in dVS, which is a commercial software system for building virtual environments (by Division Ltd). The toolkit is based on the collection of 3D widgets. The paper describes goals of development of the toolkit, logical organization of widgets and their properties and finally describes some of the widgets implemented. The paper is interesting at least becasue this work has become a real commercial product.

123. Sachs, E., Roberts, A., Stoops, D., 3-Draw: A Tool for Designing 3D Shapes. *IEEE Computer Graphics and Applications*, 1991. pp. 18-26.
Keywords: *two-handed interfaces, 3D user interfaces, sketching, 3D modeling*
Annotations: This paper describes a system for "sketching" in three dimensions using a pair of Polhemus 3Space trackers. A palette is held in one hand. A stylus held in the other hand is moved relative to it, allowing the user to sketch curves in 3D. Thus the interaction is based on two-handed manipulation of tools on "props."

124. Schmalsteig, D., Encarnacao, L., Szalzvari, Z., Using Transparent Props For Interaction with The Virtual Table. *Proceedings of Symposium on Interactive 3D Graphics*. 1999. ACM. pp. 147-154.
Keywords: *transparent props, through the plane tool, Barco Table, VR, 3D interfaces, interaction techniques*
Annotations: This paper presents a number of interaction techniques using a tracked, transparent pad. This tool is a mechanism for entering 2D input in a 3D virtual environment.

125. Schmandt, C., Spatial Input/Display Correspondence in a Stereoscopic Computer Graphic Work Station. *Proceedings of SIGGRAPH'83*. 1983. ACM. pp. 253-262.
Keywords: *VR, 3D interfaces, desktop, displays, stereoscopy, depth cues, interaction, manipulation, wand*
Annotations: This paper describes a work station designed to allow interaction with spatial correspondence between the input (Polhemus) and output (stereoscopic display) devices. The workspace consists of a monitor mounted at a 45 degree angle and a half-silvered mirror, beneath which the user holds the "wand." This set-up mixes the computer graphics and the user's hand into a single image. Pure binocular convergence was found to lack sufficient depth cues. A combination of convergence, obscurations, luminance, and size give a strong 3D sense, but no factor alone was adequate. Schmandt reports that a significant problem was lack of depth judgement. Occlusion cues were misleading, as the user could always see their hand through the semi-transparent graphics.

126. Sebrechts, M., Vasilakis, J., Miller, M., Cugini, J., Laskowski, S., Visualization of Search Results: A Comparative Evaluation of Text, 2D, and 3D Interfaces. *Proceedings of SIGIR'99*. 1999. pp. 3-10.
Keywords: *3D interface, visualization, user studies, experimental evaluation*
Annotations: The paper describes a controlled experiment to measure the effectiveness of the user interface for a system that categorizes and presents the set of documents resulting from an automatic search. 3-D, 2-D and textual variants of the interface were developed and compared.

127. Serra, L., Poston, T., Hern, N., Choon, C., Waterworth, J., Interaction techniques for a virtual workspace. *Proceedings of VRST'95*. 1995. ACM.
Keywords: *3D interaction techniques, system control, widgets, responsive workbench*
Annotations: Good overview of a large amount of 3D interaction techniques implemented on a responsive workbench. The authors also report on several implementations of techniques in medical applications.

128. Shaw, C., Green, M., Two-Handed Polygonal Surface Design. *Proceedings of UIST'94*. 1994. ACM. pp. 205-212.
Keywords: *desktop VR, 3D user interface, manipulation, two-handed input*
Annotations: Describes a system which uses two hand-held trackers (augmented with 3 buttons each) to perform CAD tasks. The dominant hand performs picking and manipulation, the non-dominant hand context setting.

129. Shaw, C., Liang, J., Green, M., Sun, Y., The Decoupled Simulation Model for Virtual Reality Systems. *Proceedings of CHI'92*. 1992. ACM.
Keywords: *software tools, virtual reality, software architectures, development toolkits*
Annotations: Describes the MR toolkit

130. Shepherd, B., Rationale and strategy for VR standards. *Proceedings of VRAIS'93*. 1993. IEEE. pp. 41-46.
Keywords: *VR, standards, survey, directions, 3D interaction, VR tools.*
Annotations: This paper discusses the need and rationale for standards in VR field: why standards are needed, what should be standardized, and what are the current (i.e. in 1993) efforts in developing standards. The author suggests that standards for VR will stabilize VR market, because it will help the software developers and hardware producers in easier integration of different products. It will also help customers since it will allow the purchase of technology without or at least with less worries technology will become obsolete, incompatible and unusable as the VR technology is developed. The areas that would benefit from standardization, according to the author, are user interfaces and software interfaces.

131. Shoemake, K., ARCBALL: a user interface for specifying three-dimensional orientation using a mouse. *Proceedings of Graphics Interface'92*. 1992. pp. 151-156.
Keywords: *desktop 3D user interface, 3D rotations, interaction technique, mouse*
Annotations: Describes a 2D interface for 3D orientation. The key is that mouse motion is consistently interpreted as a half-arc length rotation on an imaginary sphere, resulting in an interface free from hysterisis. A circle is drawn around the object being rotated; rotation about the axis perpendicular to the screen is handled by moving the mouse in the region outside of this circle. The paper also demonstrates how to add constrained rotations to the technique.

132. Sims, D., Osmose: Is VR Supposed to be this Relaxing? *Computer Graphics and Applications*, 1996. 16(6): pp. 4-5.
Keywords: *VR, art, navigation*
Annotations: Osmose was one of the first and one of the most compelling art-oriented VR environments. According to one of the authors: "Osmose is a space for exploring

the perceptual interplay between self and world, i.e. a place for facilitating awareness of one's own self as embodied consciousness in enveloping space. " From the interface point of view, the Osmose introduced an intersting navigating technique that used balance and breating for "floating" in the VE. The user was wearing a device on the chest which allowed to detect the breating patterns. By breathing in, the user was able to float upward, by breathing out, to fall, and by altering the body's center of balance, to change direction. The technique was borrowed from the scuba diving practice of buoyancy control.

133. Slater, M., Davidson, A., Liberation from Flatland: 3D Interaction Based on the Desktop Bat. *Proceedings of Eurographics '91*. 1991. Elsevier Science Publishers B.V. (North Holland). pp. 209-221.
Keywords: *3D interaction, interaction devices, desktop virtual environments*
Annotations: An early example of a desktop control device designed for 3D tasks. A 5dof device consisting of a dome on top of a mouse base. Discussion of utility of such a device for 3D control tasks.

134. Slater, M., Steed, A., 3D Interaction with the Desktop Bat. *Computer Graphics Forum*, 1995. 14(2): pp. 97-104.
Keywords: *3D interaction, interaction devices, virtual environments, bat*
Annotations: The paper presents interaction methods for locomotion, selection and manipulation that can be used with a 5dof desktop control device, the Desktop Bat. These methods are evaluated over a series of characteristic VE tasks.

135. Slater, M., Usoh, M., Body Centred Interaction in Immersive Virtual Environments. In *Virtual Reality and Artificial Life*, M. Magnenat-Thalmann and D. Thalmann, Editors. 1994, John Wiley.
Keywords: *body interaction, natural gestures*
Annotations: The authors propose gestures made by the whole body as a consistent metaphor for interaction within virtual environments.

136. Slater, M., Usoh, M., Steed, A., Taking Steps: The influence of a walking metaphor on presence in virtual reality. *ACM Transactions on Computer-Human Interaction*, 1995. 2(3): pp. 201-219.
Keywords: *presence, navigation, wayfinding, physical movement, VR*
Annotations: Authors describe how physically walking influences the feeling of presence in a virtual environment. The article also deals with the usage of a virtual body in a virtual environment, and its effects on presence.

137. Slater, M., Usoh, M., Steed, A., Taking Steps: The Influence of a Walking Technique on Presence in Virtual Reality. *Transactions on Computer-Human Interaction*, 1995. 2(3): pp. 201-219.
Keywords: *locomotion, travel, natural interaction, virtual environment, presence, immersion*
Annotations: A study on whether a more natural movement technique increases presence

138. Smith, S., Duek, D., MAssink, M., The Hybrid World of Virtual Environments. *Computer Graphics Forum*, 1999. 18(3): pp. 297-308.
Keywords: *interaction techniques, software engineering, hybrid systems, prototyping*
Annotations: The authors suggest that virtual environments can be described within a hybrid system model. They discuss how hybrid system modeling techniques can be applied to the description of virtual interaction techniques.

139. Snibbe, S., Herndon, K., Robbins, D., Using deformations to explore 3D widget design. *Proceedings of SIGGRAPH'92*. 1992. ACM. pp. 351-352.
Keywords: *3D widgets, 3D interaction, 3D user interfaces, interactive deformations.*
Annotations: 1. Early article on 3D widget design issues, showing a set of new 3D widgets to control deformations called racks. 2. One of the widget papers from Brown CG group. See also Conner, et al. 1992 and Zeleznik, et al. 1994

140. Song, D., Norman, M., Nonlinear interactive motion control techniques for virtual space navigation. *Proceedings of VRAIS'93*. 1993. IEEE. pp. 111-117.
Keywords: *virtual reality, navigation, 3D user interfaces, interaction techniques, viewpoint control*
Annotations: The paper presents an interaction technique for navigation in virtual environments, using function that non-linearly maps displacement of the head into the traveling speed.

141. Stanney, K., Realizing the full potential of virtual reality: human factors issues that could stand in the way. *Proceedings of VRAIS'95*. 1995. IEEE Computer Society. pp. 28-34.
Keywords: *3D interaction, conceptual models, experimental studies, human factors, user interface, virtual reality, VR, simulator sickness, survey*
Annotations: A survey paper describing various VR systems and techniques with respect to their adherence to human factors guidelines.

142. Stassen, H., Smets, G., Telemanipulation and Telepresence. *Proceedings of 6th IFAC/IFIP/IFORS/IEA Symposium on Analysis, Design, and Evaluation of Man-machine System*. 1995. pp. 13-23.
Keywords: *3D manipulation, telepresence, survey, theory*
Annotations: A survey of 3D manipulation and perception work from the teleoperation point of view. Touches on: 3D perception (Softenon children: without manipulation, children don't develop 3 perception), theories of perception, television (adapting to teleoperation tasks), telemanipulation: handedness, field of view & depth, time delay, implementation. Interesting work in handedness has been done in the rehabilitation field, especially in design of arm prostheses.

143. Stevens, M., Zeleznik, R., Hughes, J., An architecture for an extensible 3D interface toolkit. *Proceedings of UIST'94*. 1994. ACM. pp. 59-67.
Keywords: *user interface toolkit, software toolkit, visual programming, 3D widget, 3D user interfaces, 3D interaction, interaction techniques, direct manipulation*
Annotations: Describes the architecture and implementation details of the 3D user interface toolkit developed at Brown (see Zeleznik, et al., 1993).

144. Stoakley, R., Conway, M., Pausch, R., Virtual reality on a WIM: interactive worlds in miniature. *Proceedings of CHI'95*. 1995. pp. 265-272.

Keywords: *3D interaction, 3D user interface, 3D widgets, direct manipulation, interaction techniques, navigating, user interface, viewpoint control, virtual reality, VR.*
Annotations: 1. The original WIM (World In Miniature) paper describing the technique for manipulating world objects by moving small iconic versions of those objects in a scale model of the world 2. Describes the Worlds in Miniature interface metaphor. Augments an immersive head tracked display with a hand held miniature copy of the virtual environment; there is a 1:1 relationship between life-size objects in the virtual world and miniature objects on the hand-held miniature world.

145. Strauss, P., Carey, R., An object-oriented 3D graphics toolkit. *Proceedings of SIGGRAPH'92*. 1992. ACM. pp. 341-347.
Keywords: *3D interaction, Open Inventor, 3D interface toolkit, 3D user interface, 3D widgets, direct manipulation, interaction techniques, 3D computer graphics, graphics toolkit, scene graph*
Annotations: This is an original paper that reported software toolkit that become SGI Open Inventor tool. The toolkit pioneered using scene graph of scene representation as well as incorporation of interaction techniques in the toolkit: the toolkit featured handle boxes, techniques for interactive 3D object rotation and other techniques. The techniques, however, are designed for the desktop 3D interaction using mouse.

146. Stuart, R., *The design of virtual environments*. 1996: McGraw Hill. pp. 274.
Keywords: *virtual reality, design, 3D input and output devices, interaction techniques, human factors.*
Annotations: This book survey a large range of issues relating to design and implementation of virtual reality applications, including devices, interaction, human factors, social factors, software tools and so on. The book is somewhat outdated when it comes to interaction techniques, but still it is a good survey.

147. Sutherland, I., The Ultimate Display. *Proceedings of IFIP Congress*. 1965. pp. 505-508.
Keywords: *VR, head-mounted display, HMD*
Annotations: Another seminal VR paper

148. Sutherland, I., A Head-mounted Three Dimensional Display. *Proceedings of Fall Joint Computer Conference*. 1968. pp. 757-764.
Keywords: *VR, HMD*
Annotations: The seminal VR paper -- discusses technical details of Sutherland's original see-through display system

149. Szalavari, Z., Gervautz, M., The Personal Interaction Panel - a Two-Handed Interface for Augmented Reality. *Computer Graphics Forum*, 1997. 16(3): pp. 335-346.
Keywords: *Two-handed interaction, augmented reality, pen and pad interfaces*
Annotations: A tracked pen and pad input device that supports inteaction with different types of virtual widgets. Some example applications are given.

150. Takemura, H., Tomono, A., An Evaluation of 3-D Object Pointing Using a Field Sequential Stereoscopic Display. *Proceedings of Graphics Interface'88*. 1988. pp. 112-118.
Keywords: *experimental studies, pointing, stereoscopy, depth effect*
Annotations: Describes user experiments (six subjects) to measure performance in 3-D object pointing with stereoscopy.

151. Tarlton, M., Tarlton, P., A Framework for Dynamic Visual Applications. *Proceedings of Symposium on Interactive 3D Graphics*. 1992. ACM. pp. 161-164.
Keywords: *Software toolkit, architecture*
Annotations: Describes the Mirage system, a precursor to Inventor

152. Thorndyke, P., Hayes-Roth, B., Differences in spatial knowledge obtained from maps and navigation. *Cognitive Psychology*, 1982. 14: pp. 560-589.
Keywords: *Spatial knowledge, navigation, cues*
Annotations: This article, although it does not directly deal with VR and 3D interfaces, is one of the major references for most of the theories concerning spatial knowledge, wayfinding, spatial awareness within virtual environments . The authors developed a strong framework and especially their map-test is noteworthy.

153. Turner, R., Gobbetti, E., Soboroff, I., Head-tracked Stereo-Viewing with Two-Handed Interaction for Animated Character Construction. *Computer Graphics Forum*, 1996. 15(3): pp. 197-206.
Keywords: *Two-handed input, virtual tools, character modeling*
Annotations: A combination of a Spaceball and a 3D mouse are used to manipulate virtual tools for the construction of animated characters.

154. Usoh, M., Arthur, K., Whitton, M.C., Bastos, R., Steed, A., Slater, M., Brooks, F.P. Jr, Walking > Walking-in-Place > Flying in Virtual Environments. *Proceedings of SIGGRAPH '99*. 1999. ACM. pp. 359-364.
Keywords: *Presence, locomotion, virtual reality, virtual walking, human factor, neural networks, visual cliff*
Annotations: Comparison of three locomotion techniques for virtual reality: point and fly, virtual walking (virtual treadmill) and real walking using a wide area ceiling tracker. Virtual walking and real walking are significantly different from point and fly.

155. Verlinden, J., Bolter, J., der-Mast van, C., Virtual annotation: verbal communication in virtual reality. *Proceedings of European Simulation Symposium*. 1993. SCS Ghent, Belgium. pp. 305-310.
Keywords: *virtual annotation, verbal communication, virtual reality, simulations, visualizers, voice annotation, virtual environments*
Annotations: 1. The paper describes a system that offers a method to embed verbal communication in virtual environments by means of voice annotation. The prototype demonstrates that the addition of verbal communication opens up a range of new uses for virtual environments and it enables reading, writing and communicating. 2. The paper describes an idea and a prototype. More complete implementation of this work is described later in Harmon, et al. 1996

156. Viega, J., Conway, M., Williams, G., Pausch, R., 3D Magic Lenses. *Proceedings of UIST'96*. 1996. ACM. pp. 51-58.
Keywords: *Magic Lenses, transparent user interfaces, 3D interaction, virtual reality, VR, clipping.*
Annotations: Good article on porting Magic Lenses idea to a 3D environment. Two types of Magic Lenses was in-

troduced: flat lenses in 3D environment, and volumetric lenses in 3D environment.

157. Waller, D., Hunt, E., D., K., Measuring spatial knowledge in a virtual environment: Distances and angles. *Proceedings of 39th Annual Meeting of the Psychonomics Society*. 1998. pp. 129-143.
Keywords: *spatial knowledge, wayfinding, distance and angle estimation*
Annotations: Article on the differences of distance and angle estimations within real and virtual environments [see also Henry, 1993]

158. Waller, D., Hunt, E., Knapp, D., The transfer of spatial knowledge in virtual environment training. *Presence: Teleoperators and Virtual Environments*, 1998. 7(2): pp. 129-143.
Keywords: *Wayfinding, spatial knowledge, knowledge transfer, VR*
Annotations: Noteworthy article on the transfer of spatial knowledge between virtual environments and the real world. Focuses especially on distance angle biases.

159. Ware, C., Using hand position for virtual object placement. *Visual Computer*, 1990. 5(6): pp. 245-253.
Keywords: *3D interface, interaction techniques, manipulation, VR, multiple DOF*
Annotations: This paper describes two experiments which investigate the use of six degree of freedom digitizers (Polhemus) to manipulate 3D virtual environments. Specifically, the experiments test the speed and accuracy of placing an object in space with the correct orientation. Motions always had a total magnitude of 9.5 cm. Four subjects participated in the study. In the first experiment subjects were told to position the object (both position and orientation) as accurately as possible. Four conditions were tested: z translation enabled, z disabled, stereo, no stereo. Enabling z translations slowed accurate placement: 25% with stereo, 53% without stereo. Overall, the placement times with stereopsis were 39% faster. In the second experiment, subjects were told to make the placement as quickly as possible. Times to position, orient, or (simultaneously) position and orient were tested. Ware found that subjects were able to make effective use of all six degrees of freedom (that is, time for simultaneous positioning & orientation was less than the time for separate positioning and orientation). Disabling the z translations hindered rapid placement. Stereopsis still helped. Subjects did not report fatigue with the Polhemus. Ware states this is because it was used as a relative positioning device.

160. Ware, C., Jessome, D., Using the bat: a six-dimensional mouse for object placement. *IEEE Computer Graphics&Applications*, 1988. 8(6): pp. 65-70.
Keywords: *computer graphics. mice. computer graphic equipment. six- dimensional mouse. object placement. 6-D placement. bat. placement operations. hierarchically constructed scene. visualization. manipulation. software environment.*
Annotations: 1. Reports on experiments with a Polhemus tracker. Summary of some interesting points: It is essentially impossible to achieve precise positioning using a 1:1 control ratio when the arm/hand is unsupported. Rotations of the Polhemus produce inadvertent translations. Interaction techniques which require the user to precisely control both sets of parameters simultaneously are "generally confusing." Uses "ratcheting" for large translations or rotations: a button on the bat acts as a clutch allowing or disallowing movement. 2. The pioneering research on usability of 3D input devices.

161. Ware, C., Osborne, S., Exploration and Virtual Camera Control in Virtual Three Dimensional Environments. *Proceedings of Symposium on Interactive 3D Computer Graphics*. 1990. ACM. pp. 175-183.
Keywords: *viewpoint movement, travel*
Annotations: 1. A paper surveying the early state of the art in travel techniques for 3D environments. 2. Discusses basic interaction paradigms for 3D data. Metaphors: eyeball in hand, Scene in hand, Flying vehicle control. Studies where they are appropriate.

162. Ware, C., Rose, J., Rotating virtual objects with real handles. *Transaction on Computer-Human Interaction*, 1999. 6(2): pp. 162-180.
Keywords: *3D user interface, manipulation, rotatation, virtual reality, feedback, user studies, experiments*
Annotations: Interesting studies which compared user performance in object rotation task in real and virtual worlds. A number of conditions have been varied, such as two-handed versus one-handed, matching shape of virtual and physical objects versus non-matching shape and so on. They founded 1) the rotation in the same space, i.e. when physical hand and virtual hand "overlap", is more effective 2) it was not important to match shape of virtual and physical objects 3) there was no advantage of two-handed manipulation over one-handed manipulation 4) the virtual rotation can be performed almost as quickly as real if conditions are right. Data they report can be very useful as a comparison with other studies.

163. Ware, C., Slipp, L., Exploring virtual environments using velocity control: A comparison of three interfaces. *Proceedings of 35th Annual Meeting of Human Factors Society*. 1991. HFS. pp. 300--304.
Keywords: *VR, 3D interfaces, interaction techniques, navigation*
Annotations: Compares Polhemus, Spaceball, and mouse-based interfaces. Spaceball yielded worst performance. Some users complained of fatigue after prolonged use of the Polhemus, but it still yielded the best results.

164. Watsen, K., Darken, R., Capps, M., A Handheld Computer as an Interaction Device to a Virtual Environment. *Proceedings of Third Immersive Projection Technology Workshop*. 1999.
Keywords: *palm pilot, virtual environment interaction, mobile computing*
Annotations: This paper describes how a PDA can be used to issue commands in a virtual environment such as a Cave.

165. Weimer, D., Ganapathy, S., A synthetic visual environment with hand gesturing and voice input. *Proceedings of CHI'89*. 1989. ACM. pp. 235-240.
Keywords: *Gestural input, voice input, feedback*
Annotations: Talks about glove + voice input. Their focus is on development of synthetic environment interaction techniques, as a vehicle for experimenting with more natural 3D interfaces. A table top is used as a workspace, giving a place to rest the hands, and also providing a sort of "natural" tactile feedback when "buttons" are pressed on a menu in the synthetic space. A standard monitor i used for display. Speech input was added to the interface

for three reasons: (1) people tend to use gestures to augment speech, (2) spoken vocabulary has a more standard interpretation than gestures, (3) hand gesturing and speech complement one another. Voice is used for navigating through commands, while hand gestures provide "shape" information. "There was a dramatic improvement in the interface after speech recognition was added." A thumb gesture is used as a clutching mechanism to avoid uncomfortable hand positions. The driving application is a 3D modeling system for free-form surfaces.

166. Witmer, B., Bailey, J., Knerr, B., Parsons, K., Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human-Computer Studies*, 1996. 45: pp. 413-428.
Keywords: *spatial knowledge, route knowledge, knowledge transfer*
Annotations: Great article on knowledge transfer between virtual and real environments in training, especially route knowledge.

167. Wloka, M., Interacting with Virtual Reality. In *Virtual Prototyping - Virtual Environments and the Product Development Process*, J. Rix, S. Haas, and J. Teixeira, Editors. 1995, Chapman & Hall.
Keywords: *Interaction, user interface, performance*
Annotations: The paper defines the three features that characterize virtual reality applications: immersion, rich interaction and presence. Some of the issues to achieve them are discussed, in particular multiple inputs and outputs, multiple participants, dynamic virtual worlds, user interface paradigms and performance.

168. Wloka, M., Greenfield, E., The virtual tricorder: a uniform interface for virtual reality. *Proceedings of UIST'95*. 1995. ACM. pp. 39-40.
Keywords: *interaction metaphors, commands in VEs, selection, manipulation, navigation, interaction techniques*
Annotations: 1. An attempt to create a single interaction framework for VEs using a virtual instrument. 2. Technique implements the idea of Virtual Tricorder: a universal interaction device for virtual reality which was first suggested by Henry Sowizral

169. Youngblut, C., Johnson, R., Nash, S., Wienclaw, R., Will, C., Review of Virtual Environment Interface Technology. Institute for Defense Analysis: *Technical Report IDA Paper P-3186, Log: H96-001239*. 1996.
Keywords: *input devices, display devices, virtual reality hardware*
Annotations: Although a little dated, this paper presents a comprehensive list of input and output devices for 3D user interfaces.

170. Zeleznik, R.C., Herndon, K.P., Hughes, J.F., SKETCH: an interface for sketching 3D scenes. *Proceedings of SIGGRAPH'96*. 1996. ACM. pp. 163-70.
Keywords: *SKETCH, 3D user interface. 3D scene sketching, non photorealistic rendering, gestural interface, pen and tablet input*
Annotations: 1. The SKETCH application described in the paper allows for rapidly conceptualizing and editing approximate 3D scenes. To achieve this, SKETCH uses simple non photorealistic rendering and a purely gestural interface based on simplified line drawings of primitives that allows all operations to be specified within the 3D world. 2. The classical work of using 2D gestures for 3D modeling. The basic idea is to allow the user to sketch 3D scenes using a small set of 2D gestures, that he or she simply draw on the tablet.

171. Zeleznik, R.C., Herndon, K.P., Robbins, D.C., Huang, N., Meyer, T., *et al.*, An interactive 3D toolkit for constructing 3D widgets. *Proceedings of SIGGRAPH'93*. 1993. ACM. New York, NY, USA. pp. 81-4.
Keywords: *interactive 3D toolkit, 3D widgets, deformation racks, interactive shadows, parameterized models, 3D geometries, interactive toolkit, visual programming, interactive models, interactive behavior, three dimensional widget.*
Annotations: 1. This is the first attempt to create a software toolkit for designing 3D user interfaces. The resulted 3D interfaces are based on heavy use of 3D widgets, which were also introduced by this CG group at Brown University.

172. Zhai, S., Buxton, W., Milgram, P., The "Silk cursor": investigating transparency for 3D target acquisition. *Proceedings of CHI'94*. 1994. ACM. pp. 459-464.
Keywords: *3D selection, cursor, 3D interface, desktop VR, volumetric interface*
Annotations: 1. From paper abstract: This study investigates dynamic 3D target acquisition. The focus is on the relative effect of specific perceptual cues. A novel technique is introduced and we report on an experiment that evaluates its effectiveness. There are two aspects to the new technique. First, in contrast to normal practice, the tracking symbol is a volume rather than a point. Second, the surface of this volume is semitransparent, thereby affording occlusion cues during target acquisition. The experiment shows that the volume/occlusion cues were effective in both monocular and stereoscopic conditions. For some tasks where stereoscopic presentation is unavailable or infeasible, the new technique offers an effective alternative. 2. It was the first paper that investigated volumetric selection cursors as well as semitransparent cursors.

173. Zhai, S., Milgram, P., Buxton, W., The influence of muscle groups on performance of multiple degree-of-freedom input. *Proceedings of CHI'96*. 1996. ACM. pp. 308-315.
Keywords: *6DOF input, 3D user interfaces, 3D interaction, motor control, interactive rotation, clutching, Finger mouse, glove, experimental study*
Annotations: The paper evaluates two modes of manual control in 6DOF input. In the first mode the user can use fingers in 3D object rotation, while in the second fingers are excluded, forcing the user to use the whole hand for manipulating objects (which is exactly what happens in typical VR application when magnetic sensor is attached to the data glove). The experiments showed that device that utilized fingers allowed for significantly more effective 3D object manipulation. The author suggested that design of devices for 6DOF input should invite fingers participation in input control.